Widespread Triggering of Nonvolcanic Tremor in California

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Tremor away from volcanoes (1), termed nonvolcanic tremor, reflects a fault slip regime different than that of earthquakes. Relative to radiation from earthquakes, tremor signals have longer durations, have fewer or no abrupt wave onsets, and are depleted in high frequencies. Tremor has almost exclusively been found in subduction zones: Cascadia, southwestern Japan, Mexico, Costa Rica, and Alaska; there have been very few studies in subduction zones, and tremor is preferentially observed in subduction zones, where the fault is locked and earthquakes occur and where it is slipping freely below (6). Such transition zones also exist at shallow depths both below the top few km of fault segments known to creep continuously and laterally between locked segments and those that creep for most or all of their depth. The distribution of these various behaviors is known for most faults in California. We have no clear correlation between where the faults are creeping, locked, or transitional and where tremor occurs.

Many studies have speculated that aseismic slip and tremor are related to the release of fluids from dehydration of the subducting plate (1). Given this expected correlation between fluids and nonvolcanic tremor, we examined the data from stations close to the Coso and Geysers geothermal fields. We identified signals of many triggered earthquakes, but no tremor was apparent. These findings agree with previous work on triggered earthquakes at these sites and at the hydrothermal regions in Long Valley Caldera and Mammoth Mountain (7). The lack of triggered tremor in these geothermal regions implies that high fluid pressure and/or temperatures, although they may be necessary, are not alone sufficient to produce tremor.

In interpreting our results, it is important to note where we found triggered tremor as well as where we did not. The paucity of triggered tremor in hydrothermal regions and its lack of correlation with local, ambient slip behavior suggests that very specific conditions (e.g., temperature, pressure, fluid content, and frictional properties) control where tremor and earthquakes occur. The wide geographic extent of the triggered tremor indicates that it is more common than previously recognized and that the necessary conditions exist in a wide range of tectonic environments.

References
5. Materials and methods are available as supporting material on Science Online.

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We examined all available recordings of the Denali earthquake waves from seismic stations in California. We identified triggered nonvolcanic tremor as high frequency (about 3 to 15 Hz), nonimpulsive seismic energy that pulses with the period of the passing surface waves. This energy is not associated with nearby earthquakes or with the Denali earthquake itself. We identified tremor from seven sources that we located by using tremor envelopes as input to a grid-search algorithm (5). These locations range from the desert southeast of Los Angeles to Napa Valley in the north (Fig. 1).

Although the observed tremor bursts span a large transect of California, five sources locate close to or on dominant strike-slip faults: the San Andreas, the San Jacinto, and the Calaveras faults. The Simi Valley and Napa Valley sources are likely on more minor faults. Some models of tremor associated with slow aseismic slip in subduction zones invoke frictional behaviors expected in regions transitional between where the fault is locked and earthquakes occur and where it is slipping freely below (6). Such transition zones also must exist at shallow depths both below the top few km of fault segments known to creep continuously and laterally between locked segments and those that creep for most or all of their depth. The distribution of these various behaviors is known for most faults in California.